3. Motion and Forces Exercises Solution

E1 **(a)** displacement (direction: SW; magnitude: 200 km)

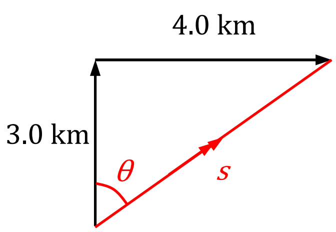
(b) speed

(c) velocity (direction: along straight edge of table; magnitude: 2 mm s^{-1})
Note: The description of the direction may be unclear (not sure exactly which direction along the straight edge) but there is undoubtedly a mention of the direction.

(d) distance

E2 Speedometer shows the speed your car is moving at.
It does not provide information on the direction of motion.

E3 Draw a vector diagram



(a) distance = 3.0 + 4.0 = 7.0 km

(b) magnitude of displacement $|s| = \sqrt{3^2 + 4^2} = 5.0$ km

$\tan\theta = \frac{4}{3} \Rightarrow \theta = 53°$

displacement is 5.0 km 53° east of north

E4 average acceleration $\bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t} = \frac{9-0}{1.5} = 6.0 \text{ m s}^{-2}$

E5 average acceleration $\bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t} = \frac{0 - \frac{115\times10^3}{60\times60}}{1.5\times60} = -0.35 \text{ m s}^{-2}$

E6 speed $= \frac{\text{distance travelled}}{\text{time taken}} = \frac{2\pi \times 1.5 \times 10^{11}}{365 \times 24 \times 60 \times 60} = 3.0 \times 10^4 \text{ m s}^{-1} = 30 \text{ km s}^{-1}$

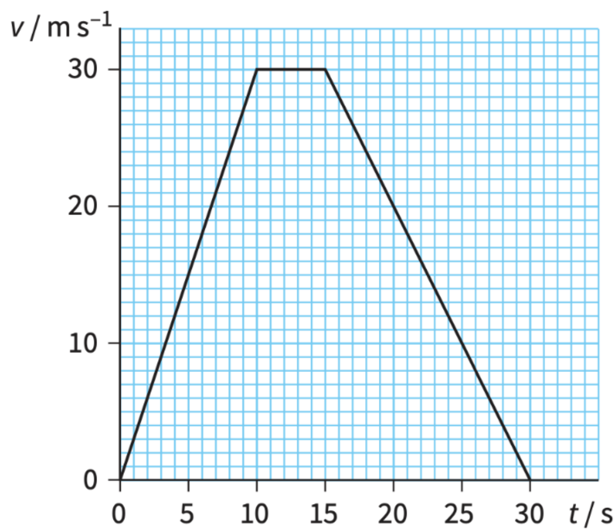
In the course of one year, its displacement is zero, so its average velocity is zero.
Note: As the Earth orbits the Sun, its direction of motion keeps changing.
Hence its instantaneous velocity keeps changing.

E7 average speed $= \frac{\text{distance travelled}}{\text{time taken}} = \frac{20 \times 2 + 40 \times 2 + 60 \times 6}{2+2+6} = 48 \text{ m s}^{-1}$

E8 s-t graph is a straight line through the origin.

velocity = gradient of s-t graph $= \frac{340-0}{4-0} = 85 \text{ m s}^{-1}$

E9 **(a)**

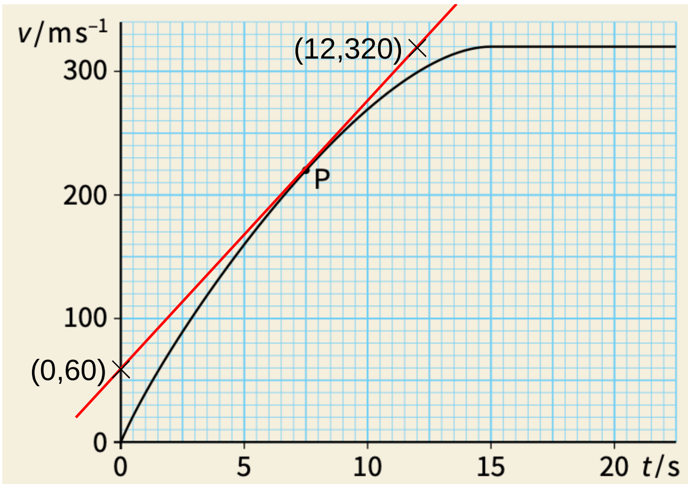


(b) acceleration for first 10 s = gradient of straight line from 0 to 10 s $= \frac{30-0}{10-0} = 3.0 \text{ m s}^{-2}$

(c) acceleration for last 15 s $= \frac{0-30}{30-15} = -2.0 \text{ m s}^{-2}$

(d) total distance = area under graph $= \frac{1}{2} \times (5 + 30) \times 30 = 525 \text{ m}$

E10 Draw a tangent to the curve at point P



acceleration $= \frac{320-60}{12-0} = 21.7 \text{ m s}^{-2}$

E11 (a) We know u, a and t and we want to know v, so we use the equation $v = u + at$.
Velocity $v = 0 + 2.0 \times 10 = 20 \text{ m s}^{-1}$

(b) We know u, a and t and we want to know s, so we use the equation $s = ut + \frac{1}{2}at^2$.
Distance $s = 0 \times 10 + \frac{1}{2} \times 2.0 \times 10^2 = 100 \text{ m}$

(c) We know u, v and a and we want to know t, so we rearrange the equation $v = u + at$.
Time $t = \frac{24-0}{2.0} = 12 \text{ s}$

E12 (a) We know u, v and t and we want to know a, so we use the equation $v = u + at$.
Acceleration $a = \frac{20-4.0}{100} = 0.16 \text{ m s}^{-2}$

(b) Average velocity $v_{avg} = \frac{v+u}{2} = \frac{20+4.0}{2} = 12 \text{ m s}^{-1}$

(c) [Method 1]
Distance = average speed × time = 12 × 100 = 1200 m

[Method 2]
We know u, v and t and we want to know a, so we use the equation $s = \frac{1}{2}(u + v)t$.
Distance $s = \frac{1}{2}(4.0 + 20) \times 100 = 1200 \text{ m}$

E13 **(a)** We know $s = 0.80$ m (↓) and $a = 9.81$ m s^{-2} (↓), and that $u = 0$, and we need to find t.
Use equation $s = ut + \frac{1}{2}at^2$ and take downwards as positive.

$$0.80 = 0 \times t + \frac{1}{2} \times 9.81 \times t^2$$

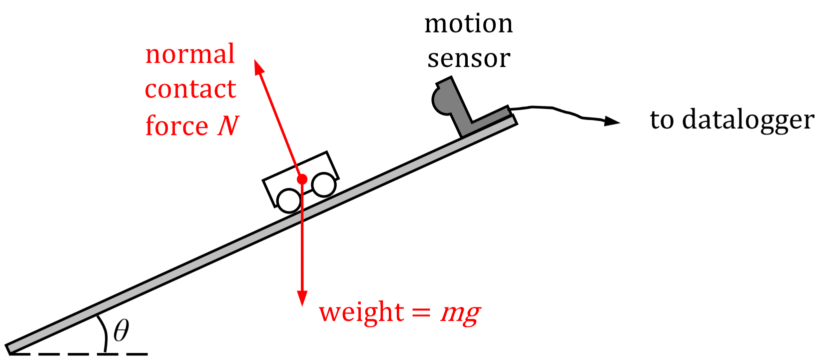
Time $t = \sqrt{\frac{2\times0.80}{9.81}} = 0.40$ s.

(b) We know $s = 0.80$ m (↓) and $a = 9.81$ m s^{-2} (↓), and that $u = 0$, and we need to find v.
Use equation $v^2 = u^2 + 2as$ and take downwards as positive.

Impact velocity $v = \sqrt{0^2 + 2 \times 9.81 \times 0.8} = 4.0$ m s^{-1}.

E14 [Method 1]
Drop an object towards the sensor, but take care not to break it
(e.g. use a softer material such as plasticine ball)

[Method 2]
A better method is to use a sloping ramp with a low friction trolley.



Resultant force = $mg\sin\theta$
Acceleration = $mg\sin\theta\,/\,m = g\sin\theta$

Gradually increase the angle of slope. Deduce the value of the acceleration when as the ramp approaches vertical ($\theta \rightarrow 90^\circ$).

E15 Define initial velocity direction as positive.

$$\text{change in momentum} = 0 - 4.5 \times 10^{-3} \times 0.12 = -5.4 \times 10^{-4}\ kg\ ms^{-1}$$

The negative implies that the average force is opposite to the initial velocity.

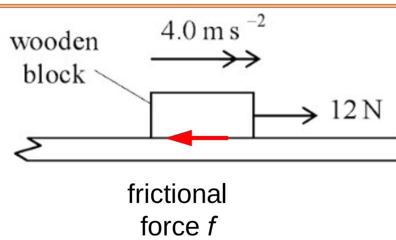
E16 Answer: D
constant velocity implies zero resultant force

E17 Answer: B
uniform acceleration means acceleration is constant

resultant force = mass × acceleration = constant

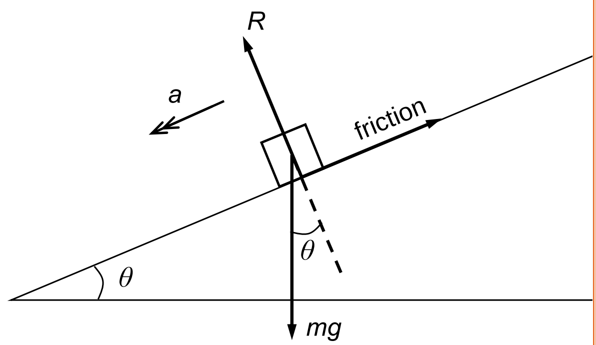
E18 Answer: B
constant velocity implies zero resultant force

E19 Answer: B
resultant force = 12 – f
ma = 12 – f
f = 12 – 0.60 × 4.0 = 9.6 N



E20 Answer: D
Resolve forces along the incline plane,

resultant force = mg sin θ – friction
ma = mg sin θ – R
a = g sin θ – R / m

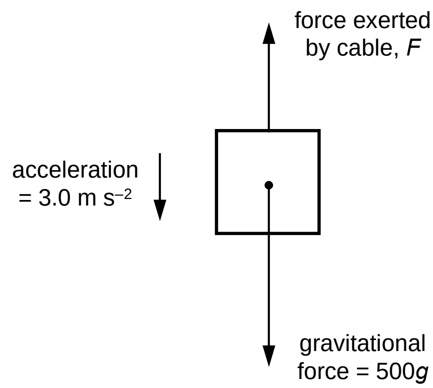


E21 **(a)** acceleration is downwards for this question, so gravitational force > force by cable

resultant force = mass × acceleration

$500 \times 9.81 - F = 500 \times 3$

$F = 3400$ N (2 s.f.)

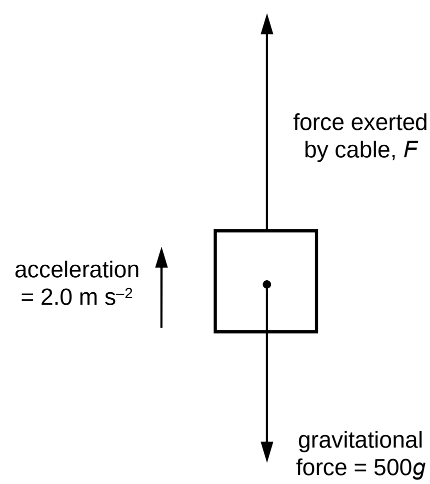


(b) even though lift is moving downwards, acceleration is upwards (since slowing down), so gravitational force < force by cable

resultant force = mass × acceleration

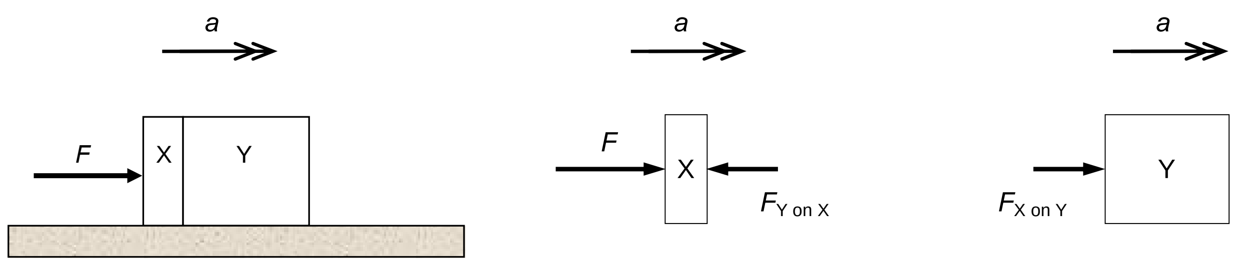
$F - 500 \times 9.81 = 500 \times 2$

$F = 5900$ N (2 s.f.)



E22 **Answer: D**

force diagrams of both masses together and individually,



(leftmost diagram) acceleration of X and Y, a = resultant force / mass = F / 4m

Consider horizontal forces on block Y,

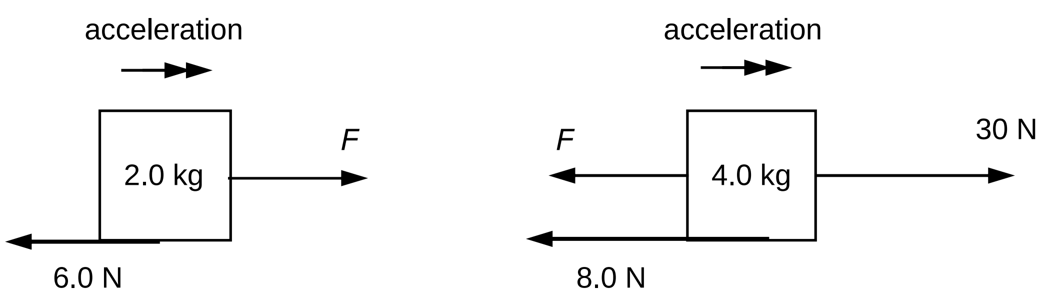
$F_{\text{X on Y}}$ = resultant force = $3ma = 3F/4$

E23 **(a)** resultant force = 30 – (6 + 8) = 16 N (right)

(b) acceleration = 16 / (2 + 4) = 2.7 m s^{-2} (2 s.f.) (right)

(c) The ends of the string (assumed massless) exert force of equal magnitude F on the blocks. The free body diagrams of the two blocks are shown.

Note: The two forces F are not action-reaction pair.



<u>Method 1 (forces acting on the 4 kg block)</u>

resultant force = mass × acceleration

$30 - F - 8 = 4 \times 2.6667$

$F = 11$ N (2 s.f.)

Force exerted by the string is <u>11N to the left</u>.

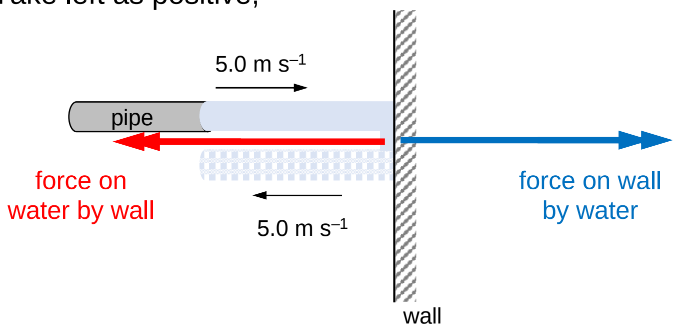
<u>Method 2 (forces acting on the 2 kg block)</u>

$F - 6 = 2 \times 2.6667$

$F = 11$ N (2 s.f.)

Magnitude of force acting by the string on the 4 kg block equals F, so the force is <u>11N to the left</u>.

E24 Take left as positive,



force on stream $F = \frac{\Delta m}{\Delta t}(v_f - v_i) = 2.0 \times [5 - (-5)] = 20$ N

By Newton's third law, force exerted by water is 20 N and directed to the right.

E25 Mass flow rate = $\frac{\Delta m}{\Delta t} = \rho A v$

Force exerted on the hose by water

= force exerted on water by hose

= $\frac{\Delta m}{\Delta t}(v_f - v_i) = \rho A v(v - 0)$

= $1000 \times \pi \left(\frac{0.01}{2}\right)^2 \times 0.50^2$

= 0.020 N